NIPPUR SULCUS REGION, GANYMEDE: NATURE OF HIGH-LATITUDE GROOVE LANES AND THEIR RELATION TO MARIUS REGIO FROM GALILEO SSI DATA.

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Background and Rationale: Nippur Sulcus is part of a complex set of groove lanes that intersect at the northern corner of Marius Regio, a polygonal region of dark terrain located in northern Ganymede (1). In Voyager data, this site contains a moderately complicated stratigraphy of superposed light terrain groove sets (e.g., Philus, Elam, Nippur, and Ur Sulci), and dark terrain, both Marius Regio proper (dark furrowed material) and patches of dark lineated/grooved material. A NW-SE regionally preferred orientation of grooved terrain (e.g., Nippur, Mashu, and parts of Elam Sulci) is generally superposed on older groove lanes having a larger variety of orientations (e.g., Philus Sulcus, Ur Sulcus, and parts of Elam Sulcus). Galileo coverage was designed to address the: 1. Detailed nature of groove morphology, 2. Origin of regional patterns of groove orientation, 3. Albedo patterns of mid-latitude light terrain (e.g., evidence for resurfacing; nature of components leading to albedo variations in bright terrain, etc.), 4. Crater morphology, 5. Light terrain stratigraphy at high spatial resolution, and 6. Light-dark terrain relationships. The specific mosaic was targeted to cross from the dark terrain of northern Marius Regio across grooved material of Philus Sulcus, into a strip of smooth material of possible cryovolcanic origin, across Nippur Sulcus, and into Elam Sulcus. Three frames, each 80 km x 80 km at a resolution of 100 m/pixel were obtained (Key observations are seen in Figure 1 at URL http://galileo.ivv.nasa.gov/sepo/atjup/ganymede/GG2 NIPPUR.html).

Observations and analysis: Dark Terrain Craters: Craters in dark terrain in general are all heavily modified by tectonic faulting with a variety of orientations. Smaller craters a few km across are commonly pervasively fractured and apparently sheared. There is a dearth of readily identifiable intermediate-sized craters. There are several places where remnants of craters between about three and fifteen km in diameter are suspected, but the tectonic deformation is so intense, they are not able to be documented confidently. A large 18 km diameter crater may be viscously relaxed; the floor appears to be at the same level as the terrain outside of the crater, suggesting relaxation from its pristine form. This crater is also deformed from its initial relatively circular shape; the western rim is largely obliterated and the remaining arc is distorted. The deformation of craters is so pervasive and intense that the process of 'tectonic resurfacing' documented in Uruk Sulcus may be important here and in the distinction of the ages of dark terrains on Ganymede and Callisto. **Dark Terrain:** The portion of dark terrain observed by Galileo was mapped as furrowed material (1) and at Voyager resolution is dominated by a NE-SW trending population of furrows, partly defining the sharp northern boundary of Marius Regio. In Galileo data these furrows are subdued compared to the rich detail of other deformation features dark terrain is highly fractured and fissured and crosscut by sinuous graben-like block faults; the background is composed of pervasive shear-like fractures. The youngest phase of deformation is a family of sinuous graben a few km in width and oriented ~N10W. This trend extends into the bright terrain and extensional deformation with this orientation was active during the emplacement of the bright terrain, decreasing in significance as a function of time. The next oldest deformation is of similar morphology but graben are narrower and more closely spaced and oriented about NS; it is best developed in the central western part of the image area. Several older deformational patterns are observed; in the central and eastern part of the dark terrain imaged, graben and fractures trending NW-SE appear to cut similar structures trending about N10E, and there is a pervasive set of very closely spaced fractures that is well developed in most of the background terrain. This set, oriented generally EW, is well developed in the eastern part of the dark terrain but is seen almost everywhere in the background terrain; the fine texture of the lineaments gives the impression of a shear fabric. Other larger more degraded linear structures are also observed trending generally EW. The dark terrain deformation observed is much more complex than previously thought from Voyager data; it is dominantly extensional, with evidence for shear parallel to the boundary of Philus Sulcus. None of the areas of smooth dark plains observed in Galileo Regio are seen here.

Bright Terrain: Crosscutting relationships in Voyager images (1) show that Nippur Sulcus forms the youngest units of bright terrain and the older bright terrain units are those of Philus Sulcus to the SW and Elam Sulcus to the NE. Galileo data show that Elam Sulcus is composed of parallel ridges and troughs continuous for distances of at least 10-20 km and arranged into at least three subparallel domains. Elam clearly predates Nippur; at the western margin of Elam, linear blocks of Elam can be seen to be slumping into Nippur and to be involved in the extension and shear deformation of Nippur. As in Uruk Sulcus, the style of tectonism has changed from an early more regular pattern (Elam) to a later pattern of extension/shear (Nippur). Philus Sulcus is similar in structure to Elam; terrain in Philus bears a strong similarity to the structures characteristic of older pitted and lineated terrain in Uruk Sulcus. In Philus, there are at least nine approximately parallel lanes of grooved terrain, 5-15 km in width. Ridges in each lane are several hundred meters apart and are often separated by troughs. In each lane, ridges are long, continuous and parallel; between adjacent lanes, ridges and troughs are oriented within a few degrees of each other. In Philus: 1) Ridges and grooves become progressively less distinct toward the middle of the deposit. In the middle lanes the surface appears relatively smooth but indistinct or subdued ridges can be seen; in some cases the surface appears to have been flooded but convincing evidence of flows, embayment, or vents have not yet been documented. 2) Troughs, likely graben, crosscut the grooved terrain orthogonally, and are parallel to the youngest deformation set in the dark terrain, although not continuous from the dark terrain. The graben in the bright terrain become progressively less distinctive toward the middle lanes, suggesting that some of the middle lanes formed at successively younger times. 3) There is evidence for obliquely cross-cutting fractures and short ridges that begin at the southern edge of the northern bright terrain graben and sweep progressively southward and eastward through the easternmost groove lanes toward Nippur Sulcus. These features appear to be crosscutting the linear elements of the groove lanes and destroying their texture in a process of tectonic resurfacing. The orientation of these shear-like features is consistent with right-lateral shear in Philus Sulcus occurring late in the history of emplacement of Philus groove lanes. On the basis of these observations we interpret the history of Philus Sulcus to be one of dominantly extension orthogonal to the strike of the groove lanes and perhaps late-stage right-lateral shear. The stratigraphically youngest sulcus, Nippur, is composed of two units; a strip of light smooth material and a broad band of bright grooved material (1). At Voyager resolution, grooved terrain is composed of 15-20 parallel, subparallel, to tangential ridges that make up the classic Voyager ridge and trough systems. At Galileo resolution, as with the Uruk Sulcus area, the course ridges and grooves are almost lost in the wealth of detail. Each ridge and trough is made up of many smaller ridges and troughs spaced several hundred meters apart. These structures are arranged in an array of patterns that are similar to some units seen in Uruk Sulcus bright terrain; taken together, a preliminary interpretation of these observations is that this terrain was deformed by extension across the strike of the ridges, and concurrent shear, producing the en echelon ridges and lensoid/sigmoidal areas within the groove lane. Transtension and dextral shear thus appear to have dominated the latter stages of the history of the formation of this portion of the bright terrain. In contrast to Philus Sulcus, where shear was more important in the latter stages of modification of the groove lanes, in Nippur shear appears to have been largely concurrent with the formation of the groove lane and heavily influenced the structural fabric of the sulcus units.

Smooth Plains: The strip of light smooth material (ls) about 15 km wide mapped from Voyager images is indeed much smoother than other sulcus surfaces at Galileo resolution. It is characterized by very sharp boundaries; it cuts the groove lanes of Philus Sulcus to the south sharply and orthogonally. To the north, the boundary is also sharp, but the structure of Nippur Sulcus is oriented tangentially and somewhat parallel. Subdued trends of both sulcus structures can be seen in the smooth terrain; a series of linear albedo stripes can be seen as extensions of the structure of groove lanes in Philus Sulcus and much sharper, but still subdued, ridge and trough structure can be seen to cross cut the Philus trend and parallel two trends in Nippur bright grooved material to the north. The surface of the light smooth material at Galileo resolution appears to have been tectonically modified by both events, but smoothed by subsequent activity, suggesting flooding. Thus, on the basis of the apparent covering of these preexisting structural trends by smooth material, this unit is interpreted to postdate the formation of Philus Sulcus and the main section of Nippur Sulcus. We as yet see no evidence for flow fronts or vents, although there is a circular structure in the northwesternmost part of the Galileo coverage that could be interpreted as a flooded crater about 4 km in diameter. In addition, one small patch of very smooth terrain occurs within Nippur Sulcus proper; this could be evidence for local cryovolcanism.

Preliminary Conclusions: 1. Dark terrain deformation is very intense and pervasive, and crater populations are so unusual, that there may be a dark terrain equivalent of the 'tectonic resurfacing' documented in the bright terrain of Uruk Sulcus. 2. Intense dark terrain deformation apparently has modified impact craters so much that this may help to explain the difference in ages between the dark terrain on Ganymede and Callisto (e.g., Ganymede underwent early intense deformation of dark terrain, Callisto did not). 3. In bright terrain, there is a change in tectonic style and orientation with time throughout the emplacement and deformation of the sulci. Shear is important late in the formation of Philus Sulcus, and apparently throughout the subsequent formation of Nippur Sulcus. 4. Bright smooth plains are the latest event in bright terrain emplacement history and are the best candidate for cryovolcanic resurfacing, although conclusive evidence is not yet at hand.

Reference: 1. S. L. Murchie and J. W. Head (1989) Geologic map of the Philus Sulcus quadrangle of Ganymede, USGS Misc. Geol. Investigation, Map I-1966.